

# Estimating Above-ground Biomass of *Melaleuca quinquenervia* in Florida, USA

T. K. VAN,<sup>1</sup> M. B. RAYACHHETRY,<sup>2</sup> AND T. D. CENTER<sup>1</sup>

## ABSTRACT

One hundred and thirty-eight *Melaleuca quinquenervia* (Cav.) S. T. Blake (broad-leaved paperbark) trees were harvested from six sites in South Florida to formulate regression equations for estimating tree above-ground dry weight. Sample trees were felled, cut, weighed, and sub-samples dried to a constant weight. Diameters of trees ranged from 0.5 to 38.6 cm, total heights from 1.3 to 25.4 m, and dry weights from 0.2 to 309.4 kg. A number of site-specific biomass equations were developed from these parameters and tested statistically. Non-linear models based on stem diameter (diameter inside bark, DIB, cm) alone explained more than 97% of the biomass (W, kg) variance, with best results obtained after two-sided logarithmic transformations. Strong site-independent correlations were observed, and a single predictive equation:  $\text{Log}_e(W) = -1.06 + 1.99 \cdot \text{Log}_e(\text{DIB})$  ( $R^2 = 0.973$ ) was statistically valid for a wide range of conditions. This equation was based on inside-bark diameter to account for differences in bark thickness which varies widely among different sites. Standing biomass of *M. quinquenervia* was estimated to vary from 129 to 263 dry mt/ha at six sites in South Florida; however, no trend seems evident among the sites in dry, seasonally wet, and permanently wet habitats. The equation described is useful in field evaluation of impacts of biological control agents, by allowing estimation of plant biomass from DIB measurements in permanent study sites where destructive sampling is not possible.

**Key words:** biological control, biomass equation, paperbark, standing crop, weed, wetland.

## INTRODUCTION

*Melaleuca quinquenervia* (Cav.) S. T. Blake (broad-leaved paperbark), native to Australia, is highly invasive in wetland habitats of South Florida, where it infests about 200,000 ha (Bodley et al. 1994). Vast areas of wetlands, including parts of the Florida Everglades, have been converted from marshes to closed-canopy *Melaleuca* forests, with major environmental and economic impacts (O'Hare and Dalrymple 1997). Current management methods include herbicide treatments, felling of mature trees or hand removal of saplings, flooding, and prescribed burning (Turner et al. 1998). High cost, non-target impacts, and the resilience of *M. quinquenervia* (epi-

cormic sprouts and massive canopy seed banks) limit the effectiveness of these methods. Biological control offers sustainable management potential by disrupting seed production, plant vitality, and growth rates, thus reducing the invasive nature of *M. quinquenervia* and rendering them more vulnerable to other environmental stresses and conventional control methods. The melaleuca snout beetle (*Oxyops vitiosa* Pascoe), a natural enemy of *M. quinquenervia* in Australia, was released in South Florida in Spring 1997 (Center et al. 2000). For field evaluation studies of biological control impacts, variations in growth rates, biomass, and productivity of *M. quinquenervia* populations must be considered.

Direct measurements of tree biomass are labor intensive, time consuming, and destructive, requiring the harvesting and handling of large amounts of plant samples. Furthermore, such destructive techniques are not suitable for studies where plants cannot be removed from the experimental plots. As an alternative, an indirect regression approach is commonly used to develop predictive equations for estimating biomass from attributes that can be measured easily. Biomass estimation has been practiced widely as a conventional part of forest inventory, and as a result, biomass equations have been developed and reported for many commercial forest trees in North America (Ter-Mikaelian and Korzukhin 1997, Ouellet 1985). However, only limited biomass data exist for exotic weedy species such as *M. quinquenervia* (Conde et al. 1981). In this paper, we present a set of regression equations for estimating above-ground biomass of *M. quinquenervia* in South Florida. This regression technique is particularly useful for predicting tree biomass in permanent plots in long-term studies to evaluate biological control agents where destructive sampling is not possible.

## MATERIALS AND METHODS

In 1997, a long-term effort to evaluate impacts of biological control agents on *M. quinquenervia* was begun. Baseline information on productivity and stand dynamics were developed for use in assessment of impacts of biological control agents. Six permanent study sites were established throughout the geographic range of *M. quinquenervia* infestation in South Florida (Figure 1) for use in various studies. The sites were selected to encompass different hydrological conditions, as hydro-pattern has been considered as a strong determinant of wetland species diversity and abundance (Mitsch and Gosselink 1986). The effects of biological control agents were evaluated by comparing paired sites in dry, seasonally wet, or permanently wet habitats. One site of each pair was designated to receive biological control agents, while the other was designated as control (no insects released) site. These

<sup>1</sup>U.S. Department of Agriculture, Agricultural Research Service, Invasive Plant Research Laboratory, 3205 College Avenue, Fort Lauderdale, FL 33314.

<sup>2</sup>University of Florida, Fort Lauderdale Research and Education Center, 3205 College Avenue, Fort Lauderdale, FL 33314. Received for publication July 1, 1999 and in revised form April 25, 2000.

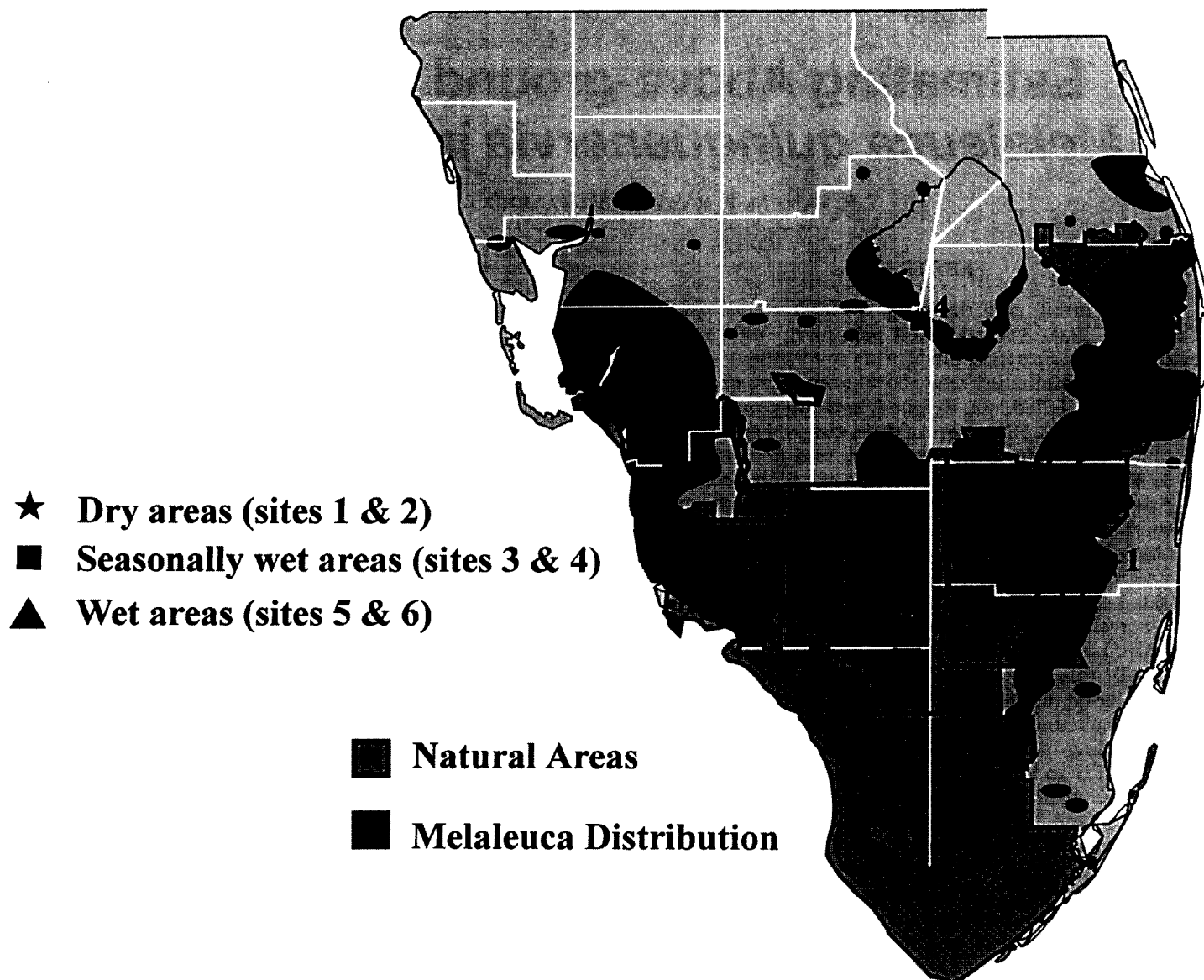


Figure 1. Location of the six natural sites used in biomass determination and their respective GPS coordinates: Site 1, Tree Top Park (26°05'N, 80°19'W); Site 2, Holiday Park (26°03'N, 80°26'W); Site 3, Thompson Park (25°55'N, 80°27'W); Site 4, Clewiston (26°47'N, 80°57'W); Site 5, Conservation Area 2B1 (26°13'N, 80°24'W); and Site 6, Conservation Area 2B2 (26°09'N, 80°21'W). Shaded areas represent the geographic range of *M. quinquenervia* infestation in Florida.

sites consist of typical 'glades' characterized by highly organic (muck) soils, the exception being Site 3 (TreeTop Park), which is an invaded pineland characterized by sandy soils.

#### Tree Measurements

One 100-m<sup>2</sup> plot was established adjacent to each of the six permanent study sites for use in biomass determination through destructive sampling. These plots were located at least 100 m inside the *M. quinquenervia* stands to avoid 'border' effect. All *M. quinquenervia* trees, 1.3 m and taller, were counted within each plot. Trunk diameters were measured at breast height, and the total basal areas were calculated for each plot. The forest understory consisted of shade-adapted

shrubs (e.g., *Myrica cerifera* L., *Myrsine guianensis* (Aubl.) Kuntz., *Baccharis* sp.), ferns (e.g., *Thelypteris* sp., *Osmunda* sp.), and grasses. Due to the sparseness and low biomass of these species, they were not considered in the analysis of biomass of the plot.

Biomass harvesting was conducted during spring 1997. From 19 to 27 trees were harvested at each of the six sites. Trees were randomly selected for biomass sampling from within all diameter classes with a goal of representing the whole range of stem diameters present within the stands. The same procedure of destructive analysis was followed at all six sites. Sample trees were felled at ground level, measured for diameter at breast height (dbh, 1.3 m) and total height, and separated into different components. Four main components were identified: trunk, branches, foliage, and capsules/seeds.

Allometric analysis of biomass partitioning into these components under different growing conditions was presented in another report (Rayachhetry et al. 2001). Plant roots were not investigated because we did not have the equipment to handle the huge roots of the sample trees. Each component harvested was weighed in the field to obtain fresh weights. A sub-sample of each component was obtained and oven-dried to a constant weight at 70°C. Dry weight/fresh weight ratios were used to estimate dry weights of the components for individual trees. Total above-ground biomass of individual tree was calculated by summing the weights of all components.

Bark thickness at dbh, and crown volume were also recorded at the time of harvest. As large variations in bark thickness were observed in *M. quinquenervia* grown at different sites (Van et al., unpubl. data), generalized biomass equations (Figure 2) that involve pooled data from several sites were presented with both outside-bark (DOB) and inside-bark (DIB) diameters. At permanently wet sites, trees were cut at the water level (0.7 m deep at harvest time). To determine the weight of the submersed stump, a stem disk (approximately 5-8 cm thick) was cut near the water level, and its dry weight was determined. Weight of the submersed stump was calculated based on the specific gravity of the stem disk and by assuming a cylindrical shape, and was added to the total above-ground biomass.

## Regression Analysis

A total of 138 trees were harvested at six study sites. Stem diameters of the harvested trees ranged between 0.5 and 38.6 cm, total heights between 1.3 and 25.4 m, and dry weights between 0.2 and 309.4 kg. Regression equations were developed from these parameters using the linear and multiple linear regression procedures of GLM (SAS 1988). First, raw data were graphed to visually assess the relationships between biomass and the independent variables. Using both raw and logarithmically transformed data, biomass was first modeled as a linear function of each independent variable, followed by step-wise addition of one or more variables if they were shown to be significant ( $p < 0.05$ ). At each step, we examined normal probability plots of residuals to test compliance of the models with the basic assumptions of least-squares regressions (Sokal and Rohlf 1981). Double-sided logarithmic transformations (natural logarithm) were applied, as it was necessary to account for the non-constant variance. Finally, corrections were made for logarithmic bias that occurs when converting from logarithmic units to arithmetic units during calculations of biomass using these log-log equations (Baskerville 1972, Sprugel 1983).

## RESULTS AND DISCUSSION

An examination of scatter diagrams and the calculation of correlation coefficients and regressions for *M. quinquenervia* showed that stem diameter at breast height provided the best estimate of tree dry weights. Adding tree height as a predicting variable in a multiple regression improved the estimate marginally, but tree heights are often difficult to determine accurately in a dense *M. quinquenervia* stand due to intermingling of canopies. Also, since multiple regression is more cumbersome to use than simple regression, stem diameter

alone is more preferable on practical grounds and was used in subsequent regression analyses.

*Melaleuca quinquenervia* above-ground biomass generally increased with increasing stem diameter. The relationship between tree weight (W, kg) and stem dbh (D, cm) was best described by an exponential curve:

$$W = a \cdot D^b \quad (1)$$

where  $a$  and  $b$  are the regression constant and coefficient, respectively. The two-sided log transformation converts the exponential model to a linear form:

$$\text{Log}_e(W) = \text{Log}_e(a) + b \cdot \text{Log}_e(D) \quad (2)$$

Whittaker and Woodwell (1968) demonstrated that equations of this form are applicable to a variety of species and have been commonly used in biomass predictions (Ter-Mikaelian and Korzukhin 1997). Table 1 presents biomass equations developed separately for *M. quinquenervia* grown at the six different sites in South Florida. Correlations between  $\log_e$  tree dry weight and  $\log_e$  outside-bark diameter (DOB) are high, i.e., larger than 97% at all sites. Senelwa and Sims (1998) pointed out that high correlations are common in biomass equations of woody species, and may be due to the fact that stem weight represents the major proportion of above-ground biomass. Shanks and Clebsch (1962) reported a correlation of  $R^2 = 0.98$  for  $\log_e$  tree weight and  $\log_e$  stem diameter in red spruce (*Picea rubens* Sarg.) from the Great Smoky Mountains. Similarly, consistently high correlations have been reported for biomass equations of several deciduous species growing under a wide range of site and stand conditions in Meathop Wood at the English Lake District in the UK (Bunce 1968). High values of correlation coefficients were also reported for sixty-five North American tree species (Ter-Mikaelian and Korzukhin 1997).

Most biomass equations are developed for specific sites, and cannot be assumed to apply to other locations. Despite this lack of generality, there is some justification for producing a generalized equation that is applicable to many sites. For example, Tritton and Hornbeck (1982) compiled biomass equations developed at different locations in the northeast U.S. and found that in most cases regressions for a given species give similar estimates. In addition, Crow (1983) reported that biomass equations for red maple in Great Lake States do not differ significantly by stand age and site index, and that a single predictive model is statistically valid for a wide range of conditions. Grigal and Kernik (1984) cautioned, however, that generalized equations work best for estimates of above-ground biomass or total biomass, but are less satisfactory for estimates of variables such as foliage biomass or crown volume that vary widely with stand conditions. Similarly in this study, analysis of variance indicated that regression equations for estimating above-ground biomass of *M. quinquenervia* did not differ significantly by sites ( $P = 0.2017$ ). As a result, it is possible to use a combined regression equation (Figure 2A) based on pooled data of all 138 sample trees to estimate standing biomass of *M. quinquenervia* for all sites:

$$\begin{aligned} \text{Log}_e(W) &= -1.83 + 2.01 \cdot \text{Log}_e(\text{DOB}) \\ R^2 &= 0.956, \text{MSE} = 0.191 \end{aligned} \quad (3)$$

# MELALEUCA STANDING BIOMASS

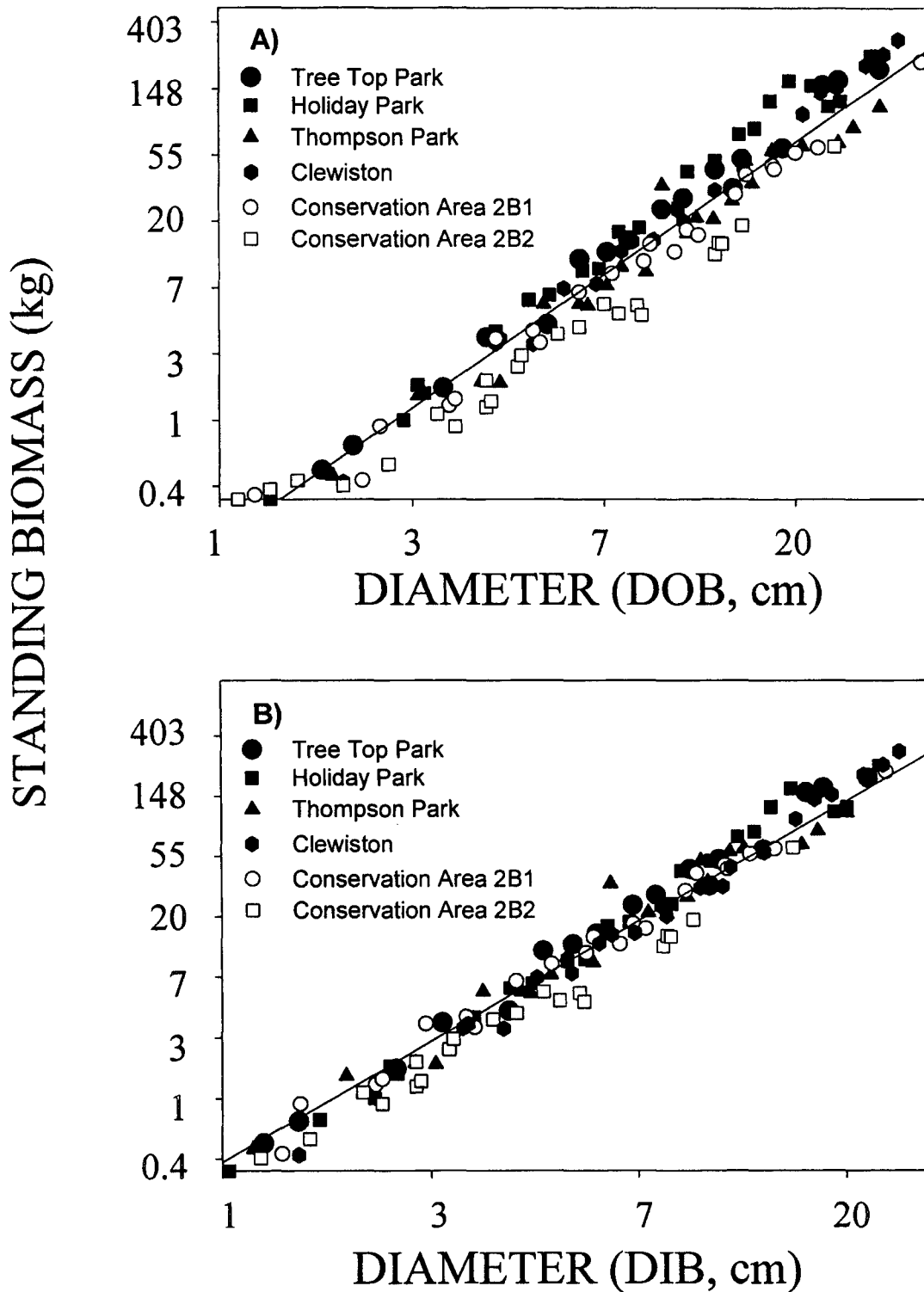


Figure 2. Log-log relationship between above-ground biomass of *M. quinquenervia* and: A) diameter outside bark (DOB) with the regression line representing Equation (3), and B) diameter inside bark (DIB) with the regression line representing Equation (4). Regression was based on destructive sampling of 138 trees from six natural sites in South Florida.

TABLE 1. REGRESSION EQUATIONS BETWEEN OUTSIDE-BARK DIAMETER (DOB, CM) AND TREE DRY WEIGHT (WT, KG) FOR *M. QUINQUENERVIA* AT SIX NATURAL SITES IN SOUTH FLORIDA.

Site no.	Site name	Regression equations	n	R <sup>2</sup>	MSE
1	Tree Top Park	Log <sub>e</sub> (WT) = -1.26 + 1.87 Log <sub>e</sub> (DOB)	19	0.979	0.151
2	Holiday Park	Log <sub>e</sub> (WT) = -1.86 + 2.21 Log <sub>e</sub> (DOB)	23	0.988	0.049
3	Thompson Park	Log <sub>e</sub> (WT) = -1.80 + 1.94 Log <sub>e</sub> (DOB)	24	0.974	0.083
4	Clewiston	Log <sub>e</sub> (WT) = -1.94 + 2.13 Log <sub>e</sub> (DOB)	22	0.988	0.047
5	Conserv. Area 2B1	Log <sub>e</sub> (WT) = -1.83 + 1.70 Log <sub>e</sub> (DOB)	27	0.969	0.091
6	Conserv. Area 2B2	Log <sub>e</sub> (WT) = -2.07 + 2.04 Log <sub>e</sub> (DOB)	23	0.988	0.054

We further determined that a generalized equation using inside-bark diameters (DIB) (Figure 2B) provides better estimates (as evidenced by lower MSE and/or higher R<sup>2</sup>) of *M. quinquenervia* standing biomass, because it accounts for differences in bark thickness which varies widely among different sites (Van et al., unpubl. data):

$$\begin{aligned} \text{Log}_e(W) &= -1.06 + 1.99 \cdot \text{Log}_e(\text{DIB}) \\ R^2 &= 0.973, \text{MSE} = 0.126 \end{aligned} \quad (4)$$

Since this broader data set covers a wide range of site and stand conditions commonly found in *Melaleuca* forests in South Florida, the Generalized Equation (4) is recommended for general use to estimate standing biomass of *M. quinquenervia* throughout its range of infestation in South Florida, providing that stem diameters, tree heights and other attributes are defined to be within those used in the data set.

Tree density of *M. quinquenervia* stands, and their distribution in diameter classes and total basal areas are given in Table 2. There are large differences in tree density between the sites. Holiday Park, Clewiston, and Conservation Area 2B2 have much lower proportions of trees in the smaller diameter classes which suggest poor regeneration. In contrast, Conservation Area 2B1 has the highest basal area and tree density, with a higher proportion of juvenile trees. Age estimates of the different stands were not made, as *M. quinquenervia* trees do not produce distinctive growth rings. Using Equation (4), we estimated standing biomass at the six different natural sites in South Florida to vary between 129 to 263 dry mt/ha (Table 2). Comparable biomass values of 122 and

170 dry mt/ha were previously reported by Conde et al. (1981) for *M. quinquenervia* based on destructive sampling of 42 trees in two small plots. Finlayson et al. (1993) used similar regression techniques and determined a total above-ground of 263 mt/ha fresh weight (approximately 132 mt/ha dry weight) in a *Melaleuca* forest on a seasonally inundated floodplain in tropical northern Australia. These biomass values approach levels similar to those reported for tropical rainforests (Yamakura et al. 1986). For comparison, an average of 121 green tons (approximately 50 mt dry) per ha of forest biomass was reported for Florida timberland (Cost and McClure 1982). However, it is doubtful that comparisons with biomass values alone have much validity in assessing productivity among different ecosystems, as productivity has a time dimension that was not addressed here.

In summary, we developed simple, but accurate, predictive equations for determination of *M. quinquenervia* tree weights based on stem diameters at breast height. These equations provide a useful tool for rapid estimation of above-ground biomass of *Melaleuca* populations in Florida. The technique described is valuable in field evaluation of impacts of biological control agents, by allowing estimation of plant biomass at permanent study sites where destructive sampling is not possible.

## ACKNOWLEDGMENTS

We thank Keith Moskowitz, Allen Dray, and Paul Madeira for technical support, and Francois LaRoche for help with field data collection. Financial support was provided by the South

TABLE 2. STAND CHARACTERISTICS AND BIOMASS OF *M. QUINQUENERVIA* AT SIX NATURAL SITES IN SOUTH FLORIDA.

Site no.	Site name	Diameter distribution (cm)						Basal area (m <sup>2</sup> /ha)	Plant density (No./ha)	Above-ground biomass (mt dry/ha)
		0-5	5-10	10-15	15-20	20-25	>25			
		(No. in a 100m <sup>2</sup> plot)								
1	Tree Top Park	209	14	7	2	3	3	94.8	23,800	143
2	Holiday Park	83	43	15	11	4	2	143.0	15,800	263
3	Thompson Park	206	45	18	12	4	1	148.8	28,600	181
4	Clewiston	59	34	7	4	1	1	78.4	10,600	129
5	Conserv. Area 2B1	1197	98	20	3	0	3	190.9	132,200	223
6	Conserv. Area 2B2	34	14	17	13	0	2	128.9	8,000	149

Florida Water Management District, Dade County Environmental Resources Management, Florida Department of Environmental Protection, and the U.S. Army Corps of Engineers.

## LITERATURE CITED

- Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. *Can J. For. Res.* 2: 49-53.
- Bodle, M. J., A. P. Ferriter, and D. D. Thayer. 1994. The biology, distribution, and ecological consequences of *Melaleuca quinquenervia* in the Everglades. In: S. M. Davis and J. C. Ogden, eds. *Everglades: The Ecosystem and Its Restoration*. St. Lucie Press, Delray Beach, FL. pp. 341-355.
- Bunce, R. G. H. 1968. Biomass and production of trees in a mixed deciduous woodland. I. Girth and height as parameters for the estimation of tree dry weight. *J. Ecol.* 56: 759-775.
- Center, T. D., T. K. Van, M. B. Rayachhetry, G. R. Buckingham, S. Wineriter, and M. Purcell. 2000. Field colonization of the melaleuca snout beetle (*Oxyops vitiosa*) in South Florida. *Biol. Control* (In press).
- Conde, L. F., D. L. Rockwood, and R. F. Fisher. 1981. Growth studies on melaleuca. In: R. K. Geiger, ed. *Proceedings of Melaleuca Symposium*. FDACS Division of Forestry, Tallahassee, FL. pp. 23-28.
- Cost, N. D. and J. P. McClure. 1982. Multi-resource inventories: Forest biomass in Florida. *USDA Forest Serv. Res. Paper SE-235*. 24 pp.
- Crow, T. R. 1983. Comparing biomass regressions by site and stand age for red maple. *Can J. For. Res.* 13: 283-288.
- Finlayson, C. M., I. D. Cowie, and B. J. Bailey. 1993. Biomass and litter dynamics in a *Melaleuca* forest on a seasonally inundated floodplain in tropical, northern Australia. *Wetlands Ecol. Manage.* 2: 177-188.
- Grigal, D. F. and L. K. Kernik. 1984. Generality of black spruce biomass estimation equations. *Can. J. For. Res.* 14: 468-470.
- Mitsch, W. J. and J. G. Gosselink. 1986. *Wetlands*. Van Nostrand Reinhold, New York.
- O'Hare, N. K. and G. H. Dalrymple. 1997. Wildlife in southern Everglades wetlands invaded by melaleuca (*Melaleuca quinquenervia*). *Bull. Florida Mus. Nat. Hist.* 41(1): 1-68.
- Ouellet, D. 1985. Biomass equations for six commercial tree species in Quebec. *Forest Chron.* 61: 218-222.
- Rayachhetry, M. B., T. K. Van, T. D. Center, and F. LaRoche. 2001. Dry weight estimation of the aboveground components of *Melaleuca quinquenervia* trees in Southern Florida. *Forest Ecol. Manage.* (In press).
- SAS Institute Inc. 1988. *SAS/STAT Procedures Guide*, Release 6.03. Cary, NC. 441 pp.
- Senelwa, K. and R. E. H. Sims. 1998. Tree biomass equations for short rotation Eucalyptus grown in New Zealand. *Biomass and Bioenergy* 13: 133-140.
- Shanks, R. E. and E. E. C. Clebsch. 1962. Computer programs for the estimation of forest stand weight and mineral pool. *Ecology* 43: 339-341.
- Sokal, R. R. and F. J. Rohlf. 1981. *Biometry* (2nd Ed.). W. H. Freeman and Co., New York.
- Sprugel, D. G. 1983. Correcting for bias in log-transformed allometric equations. *Ecology* 64: 209-210.
- Ter-Mikaelian, M. T. and M. D. Korzukhin. 1997. Biomass equations for sixty-five North American tree species. *Forest Ecol. Manage.* 97: 1-24.
- Tritton, L. M. and J. W. Hornbeck. 1982. Biomass equations for major tree species of the Northeast. *U.S. Forest Serv. Gen. Tech. Rep. NE-69*. 46 pp.
- Turner, C. E., T. D. Center, D. W. Burrows, and G. R. Buckingham. 1998. Ecology and management of *Melaleuca quinquenervia*, an invader of wetlands in Florida, USA. *Wetlands Ecol. Manage.* 5: 165-178.
- Whittaker, R. H. and G. M. Woodwell. 1968. Dimension and production relations of trees and shrubs in the Brookhaven Forests, New York. *J. Ecol.* 56: 1-25.
- Yamakura, T., A. Hagibara, S. Sukardjo, and H. Ogawa. 1986. Above-ground biomass of tropical rain forest stands in Indonesian Borneo. *Vegetatio* 68: 71-82.